Exploratory assessment of *Sardinella aurita* using data-limited methods

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1. Introduction

Last assessment of *Sardinella aurita* was carried out in 2011 at CECAF WG Small Pelagics North using the accepted model Biodyn. The available abundance indices have been discontinued since that year and as Bidoyn cannot tackle gaps in the time series, no assessment was performed since.

Abundance indices are available for the recent years, provided by the Nansen survey (2015 and 2017). Length distributions are available for years 2018-2020. This amount of information allows a multi-model approach to attempt the assessment of the status of this stock using both length- and catch-based methods.

2. Methodologies

2.1. Length-based methods

2.1.1. LBI

A set of Length-Based Indicators (LBI) is calculated for screening catch–length composition and classifying the stocks according to conservation/sustainability, yield optimization and MSY considerations. These indicators require data on the stock catch–length composition and life-history parameters. The conceptual approach was defined by Froese (2004), and the methodology was later developed by WKLIFE V (ICES, 2015) and recommended by ICES to estimate MSY reference points for data-limited stocks, considered as category 3 and/or 4 (ICES, 2018). The LBIs are calculated by year from length–frequency distributions. They are compared to appropriate reference points related to conservation, optimal yield and length distribution relative to expectations under MSY assumptions (Table 1).

Information required includes length at maturity ($L_{mat\text{-}50}$), von Bertalanffy growth parameter (L_{inf}), catch at length per year, length–weight relationship parameters (*a* and *b*) or mean weights-at-length per year.

Table 1. Selected indicators for LBI screening plots. Equation for L_{opt} in ICES (2018) *assuming *M/k*=1.

Indicator	Calculation	Reference	Indicator ratio	Expected value	Property
$L_{max5\%}$	Mean length of largest 5%	L_{inf}	$L_{max5\%}/L_{inf}$	>0.8	Conservation (large individuals)
$L_{95\%}$	95th percentile		$L_{95\%}/L_{inf}$		
P_{mega}	Proportion of individuals above Lopt + 10%	0.3-0.4	P_{mega}	>0.3	
$L_{25\%}$	25th percentile of length distribution	Lmat	$L_{25\%}/L_{mat}$	>1	Conservation (immatures)
Lc	Length at first catch (length at 50% of mode)	Lmat	Lc/L_{mat}	>1	
L_{mean}	Mean length of individuals > Lc	$L_{opt}=⅔L_{inf}$	L_{mean}/L_{opt}	≈1	Optimal yield
L_{maxy}	Length class with máximum biomass in catch	$L_{opt}=⅔L_{inf}$*	L_{maxy}/L_{opt}	≈1	
L_{mean}	Mean length of individuals > Lc	$L_{F=M}=0.75Lc+0.25L_{inf}$*	$L_{mean}/L_{F=M}$	≥1	MSY

In order to interpret and discuss correctly the results provided by the LBI approach, it is crucial to take into account that the method assumes stock equilibrium conditions (total mortality and recruitment have been constant for a period as long as the lifetime of the time series) and logistic selectivity curve (i.e. the curve is flat-topped not dome-shaped).

The LBI was run in R (R Core Team, 2021). Methodology is available at https://github.com/ices-tools-dev/ICES_MSY

2.1.2. LB-SPR

Spawning Potential Ratio (SPR) is defined as the proportion of Spawning Biomass per recruit (SBPR) of an exploited stock with regards to the SBPR of the unfished/unexploited (virgin) stock. The rationale behind is that the abundance at length in the population decreases with ageing (length) because of the natural and fishery mortality (*M* and *F*, respectively, in years^{-1}). A virgin population will have a larger amount of large mature individuals than an exploited population.

The SPR ranges between 1 (virgin population) and 0 (collapsed or extinct population).

- A SPR in the range of 0.35-0.4 is usually considered as a population at the MSY level, although this is a quite variable parameter.
- A population with SPR below 0.1-0.15 is considered collapsed.

The LBSPR method has been developed for data-limited fisheries; data requested are a representative sample of the size structure of the catch along with limited knowledge of the species' life history and the fishery. Otherwise, the LBSPR method does not require knowledge of *M*, but instead uses the ratio of this parameters and the von Bertalanffy growth rate (*k*, years^{-1}) (*M*/*k*), which is believed to vary less across stocks and species than *M* (Prince *et al.,* 2015).

LBSPR method relies on a number of simplifying assumptions (ICES, 2018):

- The LBSPR models are equilibrium based.
- The length composition data is representative of the exploited population at steady state. The selection pattern follows a logistic curve.

The LB-SPR was run in R (R Core Team, 2021). Methodology is available at https://github.com/ices-tools-dev/ICES_MSY.

2.2. Catch-based methods

2.2.1. CMSY

CMSY was developed by Martell and Froese (2013) and further evolved in Froese *et al.* (2017) as a surplus production model that in its basic form only requires a catch time series and some prior information about the stock and its status. The method requires an estimate of the resilience (r) of the stock, ranging from very low (0.015–0.1), low (0.05–0.5), medium (0.2–0.8), or high (0.6–1.5), which can be determined through expert knowledge or from resources such as FishBase (Froese and Pauly, 2021). The biomass prior information is incorporated as a start, intermediate and final biomass range as a proportion of the unexploited biomass (depletion). These can be defined using expert opinion, but the method also provides default rules to generate them. The rules for defining these biomass prior ranges can be found in Froese *et al.* (2017). From within the ranges of r and K, generated by default rules or expert opinion, CMSY selects a pair of r–K values and runs a Schaefer surplus production model for the time series from a random starting biomass randomly selected from within the starting biomass range. The r–K pair will be considered viable if the biomass does not drop below 1% of the carrying capacity, and the biomass falls within the predicted biomass prior ranges in the intermediate and final year. The process is applied to between 10000 and 200000 r–K pairs to determine the possible options for the r and K parameter pairings. The final values are selected from the tail of viable pairs, where the r value is highest. From these r and k values, the MSY, B_{MSY}, F_{MSY}, and other fisheries reference points and confidence limits are determined.

For the purpose of comparing CMSY results with the results of a regular surplus production model, we also fitted a Bayesian implementation of a state-space Schaefer model (BSM) to catch and biomass estimates. The applicability of the full Schaefer is limited to the cases in which a biomass trend is available as the model produces precise confidence levels, thus it can be considered a good reference against which the results of CMSY can be compared.

As the CMSY method is not a method based on a statistical estimation of parameters, there is no objective criterion to judge the "goodness of fit" of the model nor to compare two models. For this exercise we understand that a reliable stock assessment should be generally recognized by the following observations:

- The reconstructed biomass trend starts and ends within the prior ranges.
- There are many viable r and K points and these have a well defined "accumulation point" in the points cloud.
- The blue (CMSY) and red (BSM) point clouds overlap.
- For each inner estimation method (CMSY and BSM) there should be one point cloud only, i.e. each method produces one cluster of points (one black and another one grey).

The CMSY method requires prior information about stock's depletion at the start of the time series and the range of possible r-values for the considered species. As a proxy for r-ranges, the resilience of the species as stated in FishBase (Froese and Pauly, 2021) was used in Runs 1-3 as recommended by Froese *et al.* (2017). Moreover, r estimate taken from latest assessment of the species (performed in 2011 with Biodyn) with an arbitrary error of 20% was used in Runs 4-6. Medium starting depletion (0.2 – 0.6) was initially assumed for Run 1 and Run 4. Finally, to test the sensitivity of the CMSY assessment to the prior of starting biomass depletion, a sensitivity analysis was conducted. The priors tested corresponded to ranges of strong (0.01-0.4, Run 2 and Run 5) and low depletion (0.4-0.8, Run 3 and Run 6) as suggested by Froese *et al.* (2017).

Table 2. Details of the scenarios tested with CMSY for *Sardinella aurita* stock. Resilience ranges were obtained from FishBase (Froese and Pauly, 2021) and from Biodyn 2011 assessment (FAO, 2012) and the depletion levels (B/K) set as recommended by Froese *et al.* (2017).

Run	Time series		resilience (r)	prior initial B/K
	Landings (t)	Survey index (t)		
1	1990-2020	1995-2010 2015 2017	0.46-1.16	Medium 0.2-0.6
2				Strong 0.01-0.4
3				Low 0.4-0.8
4			0.44-0.84	Medium 0.2-0.6
5				Strong 0.01-0.4
6				Low 0.4-0.8

These scenarios of CMSY were run in R (R Core Team, 2021) using the script CMSY_2019_9f.R available on github (https://github.com/SISTA16/cmsy).

In addition, a scenario of CMSY using CPUE from Dutch fleet as biomass indicator was carried out.

Table 3. Details of the Run 7 tested with CMSY for *Sardinella aurita* stock. Resilience range was obtained from FishBase (Froese and Pauly, 2021).

<table>
<tr><th rowspan="2">Run</th><th colspan="2">Time series</th><th rowspan="2">resilience (r)</th><th rowspan="2">prior initial B/K</th></tr>
<tr><th>Landings (t)</th><th>CPUE (t/d)</th></tr>
<tr><td>7</td><td>1990-2020</td><td>1993-2016</td><td>0.46-1.16</td><td>0.5-0.8</td></tr>
</table>

2.2.2. SPiCT

SPiCT is an advanced continuous in time stochastic surplus production model which, which incorporates dynamics in both biomass and fisheries and observation error of both catches and biomass indices. Benefits of the continuous-time state-space model formulation include the ability to provide estimates of exploitable biomass and fishing mortality at any point in time from data sampled at arbitrary and possibly irregular intervals. A full description of the model can be found in Pedersen and Berg (2017).

The process part describes the dynamics of the stock and of the fishing mortality. The underlying population dynamics is represented by a Pella-Tomlinson equation, with an additional yearly random term having a standard deviation *sdb*. This term is a process error, allowing for the biomass estimated in the model to depart from the Pella-Tomlinson equation. The fishing mortality in the model is represented as a random walk process, having a standard deviation *sdf*.

The observation model relates the observations (catch and abundance indices) to the model. For the abundance indices, modeled values are calculated based on the model biomass and fishing mortality (using a catchability parameter q for each abundance index), and are compared to the actual observation values, assuming a lognormal error of standard deviation *sdi*. Catch data are treated in a similar manner, with an observation standard deviation *sdc*.

Multiple trial assessments with different configurations (Table 3) were tested as recommended within the SPiCT guidelines. No specific prior values were used for initially fitting the model (Run 1). Using the default configuration, the model failed to converge. Attempts to overcome this problem were carried out by fixing the parameter n which determines the shape of the production curve in the Pella-Tomlinson equation. A value of 2 (imposing a stock dynamic following a Schaefer model, Run 2) was tested although model was not able to converge. Catch time series was shortened from 1995 to match survey time series (Runs 3-5). Additional information was then included in the fit via prior distributions for model parameters to improve the model fit and to provide stability to the model (i.e. fixing n=2 to resemble Schaefer model ,Run 4, and a Gaussian prior imposed for the initial depletion level with mean log(0.5) and standard deviation 0.2 was imposed, Run 5).

Table 4. Details of the scenarios tested with SPiCT for *Sardinella aurita*.

<table>
<tr><th rowspan="2">Run</th><th colspan="2">Time series</th><th rowspan="2">n</th><th rowspan="2">prior initial B/K</th></tr>
<tr><th>Landings (t)</th><th>Survey index (t)</th></tr>
<tr><td>1</td><td rowspan="2">1990-2020</td><td rowspan="5">1995-2010
2015
2017</td><td></td><td></td></tr>
<tr><td>2</td><td>Fixing n=2</td><td></td></tr>
<tr><td>3</td><td rowspan="3">1995-2020</td><td></td><td></td></tr>
<tr><td>4</td><td>Fixing n=2</td><td></td></tr>
<tr><td>5</td><td></td><td>(0.5,0.2)</td></tr>
</table>

The procedure for the acceptance of a SPiCT assessment consisted in verifying:

- Model convergence.
- No violation of model assumptions based on one-step-ahead residuals (bias, autocorrelation, normality).
- All variance parameters of the model parameters are finite should be TRUE.
- Consistent patterns in the retrospective analysis.
- Realistic production curve.
- Checking that the same parameter estimates are obtained if using different initial values.
- High assessment uncertainty can indicate a lack of contrast in the input data or violation of the ecological model assumptions. The main variance parameters (logsdb, logsdc, logsdi, logsdf) should not be unrealistically high. Confidence intervals for B and F should not span more than 1 order of magnitude.

The SPiCT model was run in R (R Core Team, 2021), using the library(spict) available on github (https://github.com/fishfollower/spict).

3. Results

Input data

Data on length–frequency distribution of the landings of *Sardinella aurita* are available for the years 2018–2020 (Fig. 1, left). Length-frequency distribution of year 2019 seems to be not representative of the structure of the stock.

Information of landings (t) and biomass estimates (t) from acoustic surveys combined over the regions are also available for this stock. Landings time-series was extended back to 1990 whereas survey index is available from 1995-2010 and for years 2015 and 2017 (Fig. 1, right).

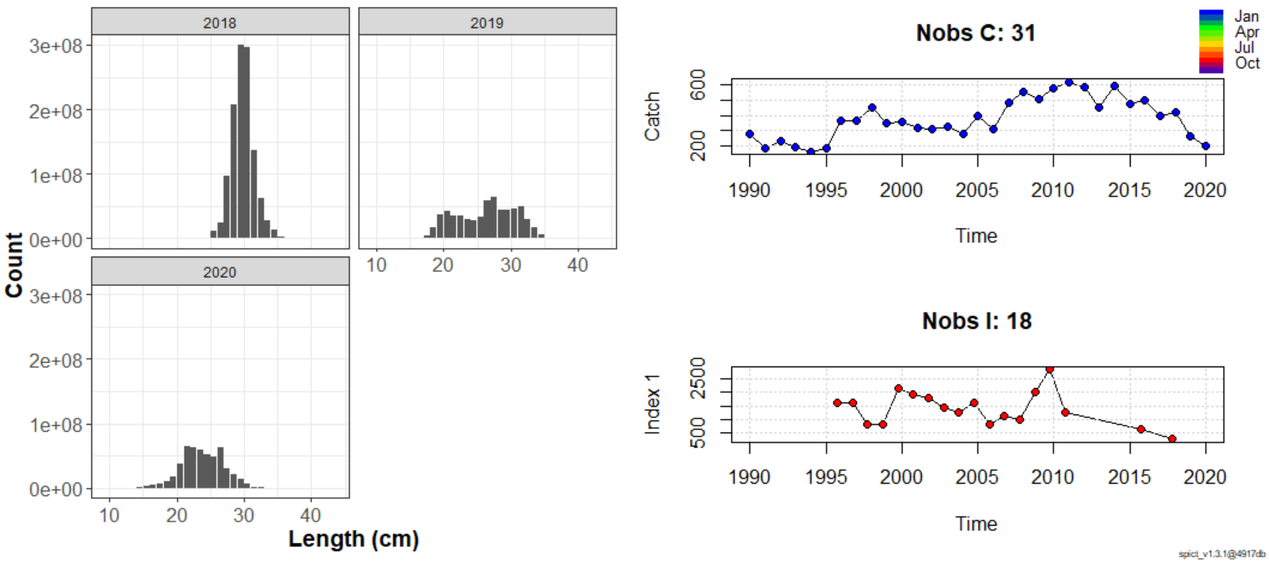


Figure 1. Input data for the *Sardinella aurita*. Left: Annual length–frequency distributions of the landings 2018-2020. Right: Annual fishery data (1990-2020) and acoustic survey biomass estimates over the entire region (1995-2010, 2015, 2017).

3.1.1. LBI

Input data

The values of the life-history parameters of *Sardinella aurita* derived from Deme *et al.,* 2012 are the following:

- M=0.45 years^{-1} and k=0.45 years$^{-1.}$ Therefore, M/k=1
- L_{inf}=40 cm
- L_{mat-50}=24.4 cm
- length–weight relationship parameters a=0.0061 and b=3.29

The LBI method adjusted using the above values is termed 'reference model'.

Table 5. Traffic-light indicators for *Sardinella aurita.*

	Conservation				Optimizing Yield	MSY
Year	L_c / L_{mat}	$L_{25\%}$ / L_{mat}	$L_{max\,5}$ / L_{inf}	P_{mega}	L_{mean} / L_{opt}	L_{mean} / $L_{F=M}$
2018	1.17	1.17	0.84	0.04	1.01	0.93
2019	0.80	0.92	0.84	0.04	0.89	1.01
2020	0.84	0.88	0.75	0.00	0.81	0.90

From Table 5 it is observed that L_c was generally below L_{mat} indicating no opportunity to spawn before than fish are available to the fishery. Indication of depletion of large animals is observed as proportion of mega-spawners is low. The LBIs and reference points obtained suggested that the level of exploitation of the stock (expressed by mean length in the catch, L_{mean}) was below to the potential FMSY targets of L_{opt} or $L_{F=M}$. The value of L_{mean} is far from L_{opt}, then the fishery is operating with a target length that is not sustainable and therefore far from MSY.

Sensitivity analysis

A sensitivity analysis of the parameters L_{inf}, M/k and L_{mat-50} (around the reference values) was carried out overestimating and underestimating them a 5 and 10 percentages. For shortness of the document, results are summarized and not shown here. Underestimation of L_{inf} led to a slightly better perception of the stock in terms of optimal yield and MSY. Overestimation of L_{mat-50} led to a decrease in the values of the indicators related to the conservation of immature.

3.1.2. LB-SPR

For this analysis we used the following values of the life-history parameters considered for the *Sardinella aurita* derived from Deme *et al.,* 2012:

- M=0.45 years^{-1} and k=0.45 years^{-1}. Therefore, M/k=1
- L_{inf}=40 cm
- L_{mat-50}=24.4 cm
- L_{mat-95}=30 cm

The LBSPR model adjusted using the above values is termed 'reference model'.

The evolution of F/M and SPR is presented in Figure 2, indicating heavy exploitation during the years. SPR of *Sardinella aurita* resulted below the SPR range of 30–40% for the entire time series.

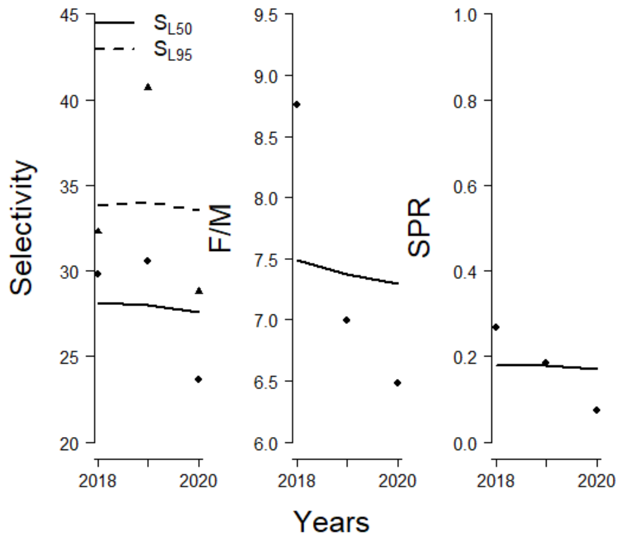


Figure 2. LB-SPR outputs for *Sardinella aurita*. Estimates of: (left) selectivity; (centre) F/M, and (right) SPR.

Sensitivity analysis

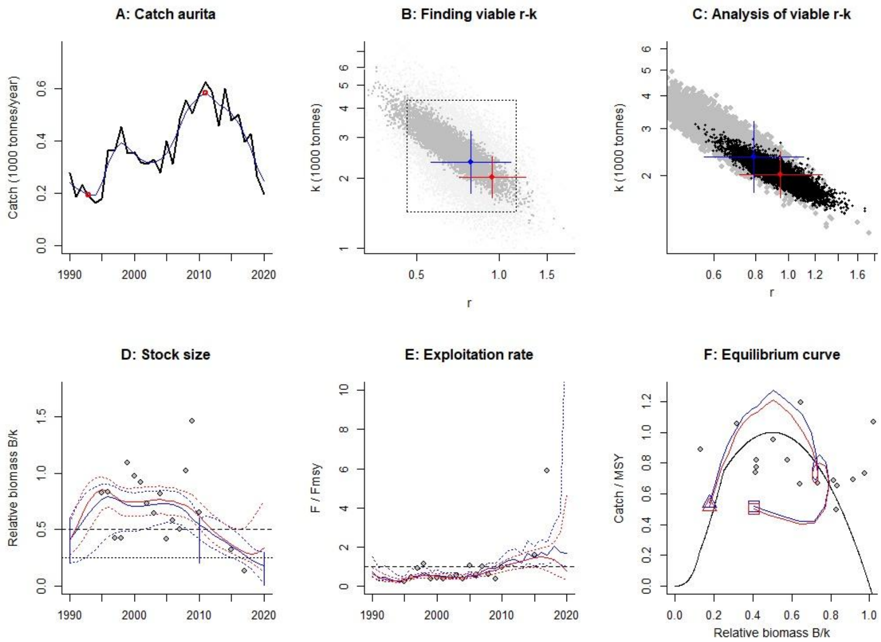
A sensitivity analysis of the parameters L_{inf}, M/k and L_{mat-50}, L_{mat-95} (around reference values) is carried out overestimating and underestimating them a 5 and 10 percentages. For shortness of the document, results are summarized and not shown here. Underestimation of L_{inf} led to a slightly better perception of the stock in terms of SPR. On the other hand, the parameters *M*/k, L_{mat-50} and L_{mat-95} have also an effect on the results but softer.

3.1.3. CMSY

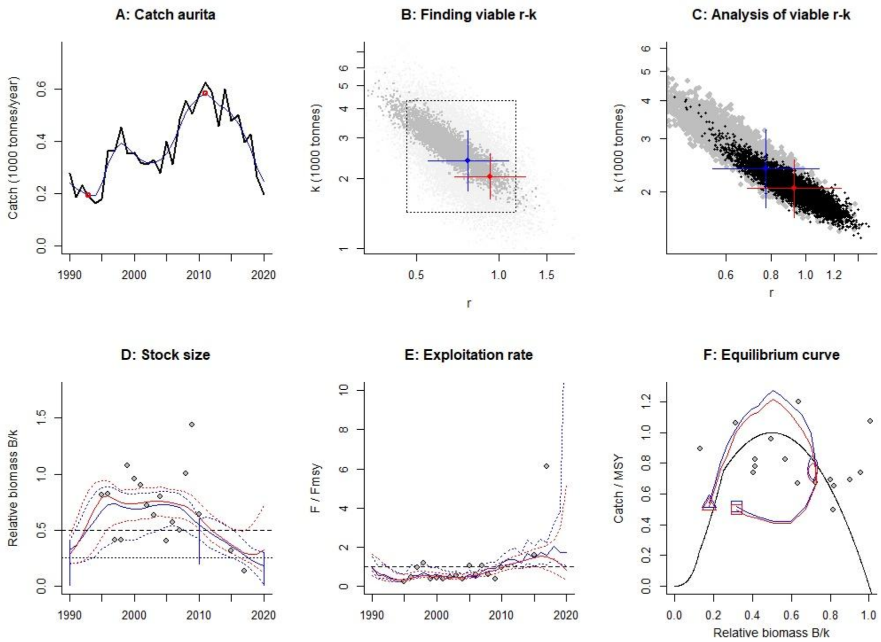
The annual landings of *Sardinella aurita* over the period 1990-2020 were used to apply CMSY, with the different combination of priors previously shown in Table 2. For the BSM, acoustic estimates provided by surveys conducted in the entire region were used (time series 1995-2010 and years 2015 and 201).

Based on the results shown in Figure 5, it appears that regardless prior assumptions the estimated biomass trajectory is descendent and stock status in the terminal year is well below Bmsy.

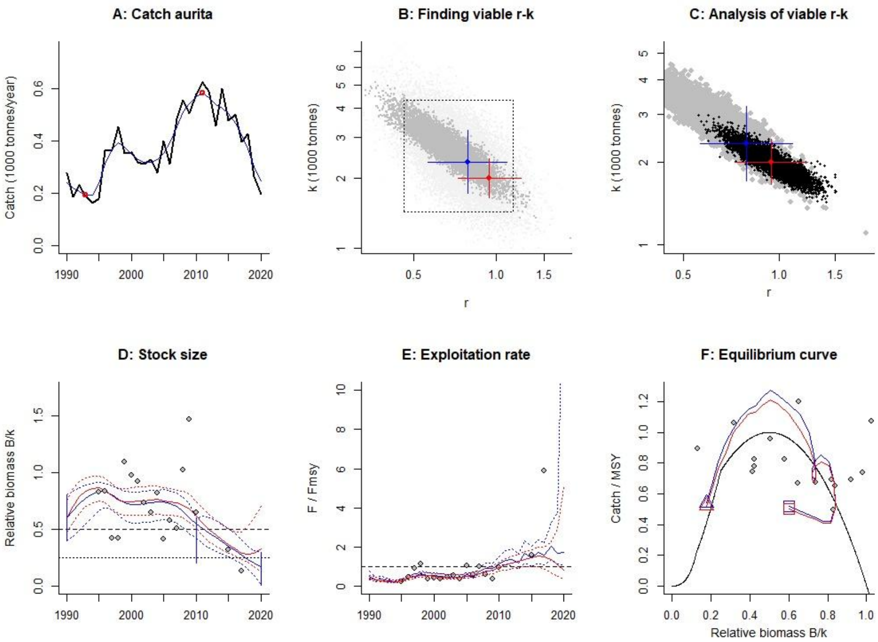
Run 1


A: Catch aurita
B: Finding viable r-k
C: Analysis of viable r-k
D: Stock size
E: Exploitation rate
F: Equilibrium curve
Catch (1000 tonnes/year)
k (1000 tonnes)
r
Relative biomass B/k
F / Fmsy
Catch / MSY

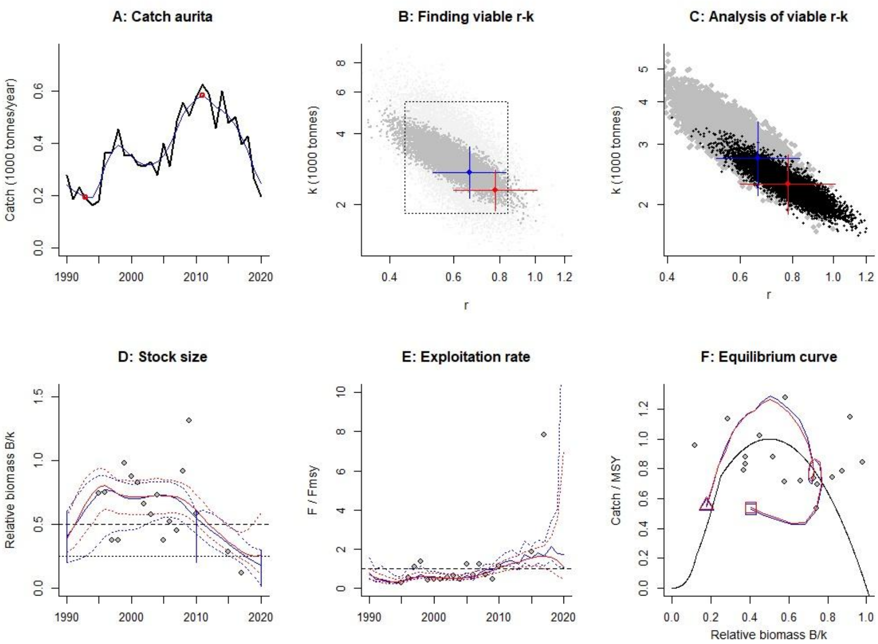
Run 2


A: Catch aurita
B: Finding viable r-k
C: Analysis of viable r-k
D: Stock size
E: Exploitation rate
F: Equilibrium curve
Catch (1000 tonnes/year)
k (1000 tonnes)
r
Relative biomass B/k
F / Fmsy
Catch / MSY

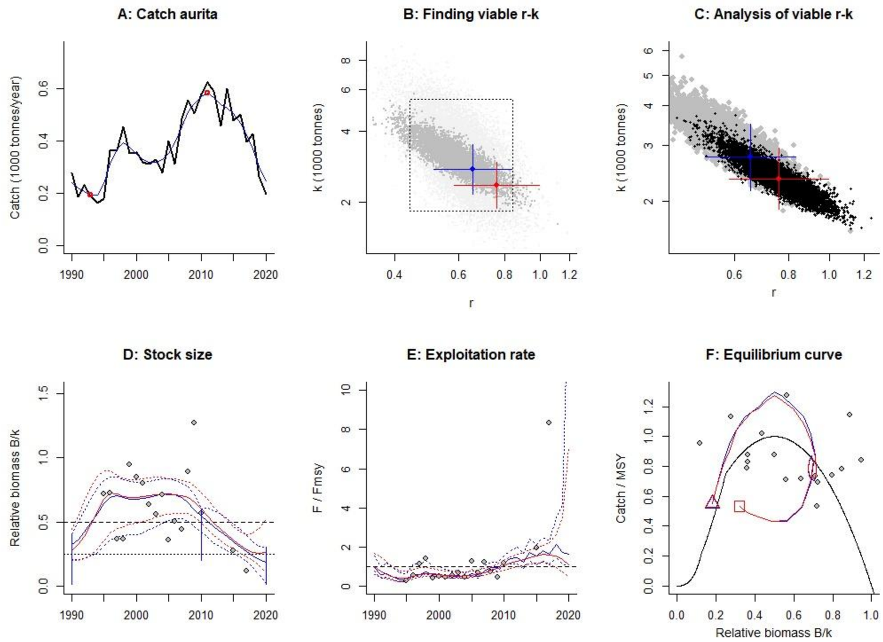
Run 3


A: Catch aurita
B: Finding viable r-k
C: Analysis of viable r-k
Catch (1000 tonnes/year)
k (1000 tonnes)
r
D: Stock size
E: Exploitation rate
F: Equilibrium curve
Relative biomass B/k
F / Fmsy
Catch / MSY
Relative biomass B/k

Run 4


A: Catch aurita
B: Finding viable r-k
C: Analysis of viable r-k
Catch (1000 tonnes/year)
k (1000 tonnes)
r
D: Stock size
E: Exploitation rate
F: Equilibrium curve
Relative biomass B/k
F / Fmsy
Catch / MSY
Relative biomass B/k

Run 5



Run 6

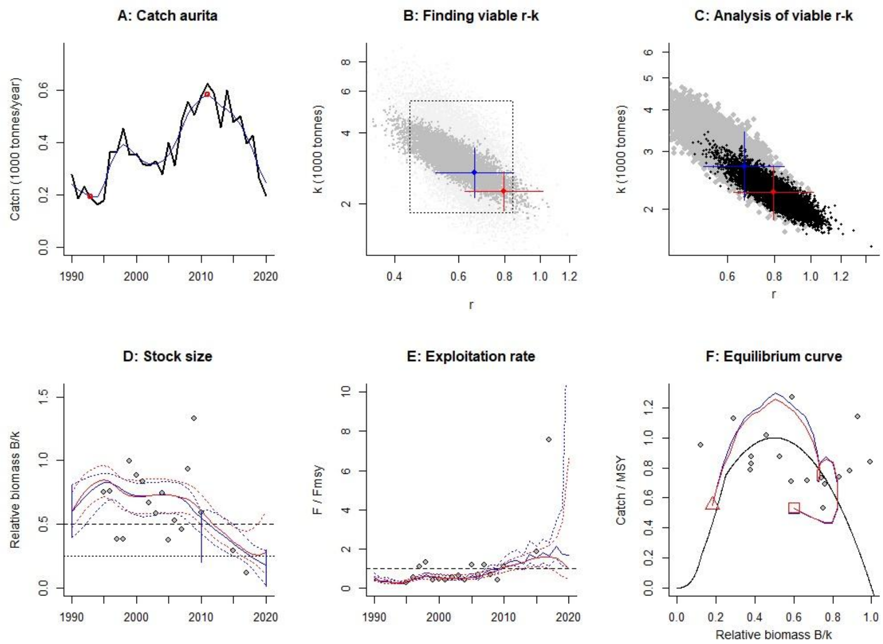


Figure 5. CMSY and BSM outputs for *Sardinella aurita* for Runs 1-6.The black curve in **A** shows the time series of catches and the blue curve shows the smoothed data with indication of highest and lowest catch in red, as used in the estimation of prior biomass by the default rules. Panel **B** shows the explored log *r-k* space and in dark grey the *r-k* pairs which were found by the model to be compatible with the catches and the prior information (the blue and red cross indicate the best *r-k* estimate of CMSY and BSM respectively). The dotted rectangle indicates the range of the priors provided. The point in the center of the blue and red cross is the most likely r-k pair predicted by CMSY and BSM and horizontal and vertical error bars approximate 95% confidence limits for *r*

and *k,* respectively, which are again closer view in Panel **C**. The blue curve in **D** shows the median of the biomass trajectories estimated by CMSY and BSM. Dotted lines indicate the 2.5th and 97.5th percentiles. Vertical blue lines indicate the prior biomass ranges. Panel **E** shows median exploitation (*F/Fmsy*) as blue curve, with the dotted curves indicating 2.5th and 97.5th percentiles. The steep increase in the upper confidence limit in the last year results from catch relative to the lower confidence limit of biomass in panel **D**. Panel **F** shows the Schaefer equilibrium curve of catch/MSY relative to *B/k*, indented at *B/k* < 0.25 to account for reduced recruitment at low stock sizes. The blue curve shows the predictions by CMSY whereas red curve corresponds to BSM, both from first year (square) to last years (triangle).

Run 7

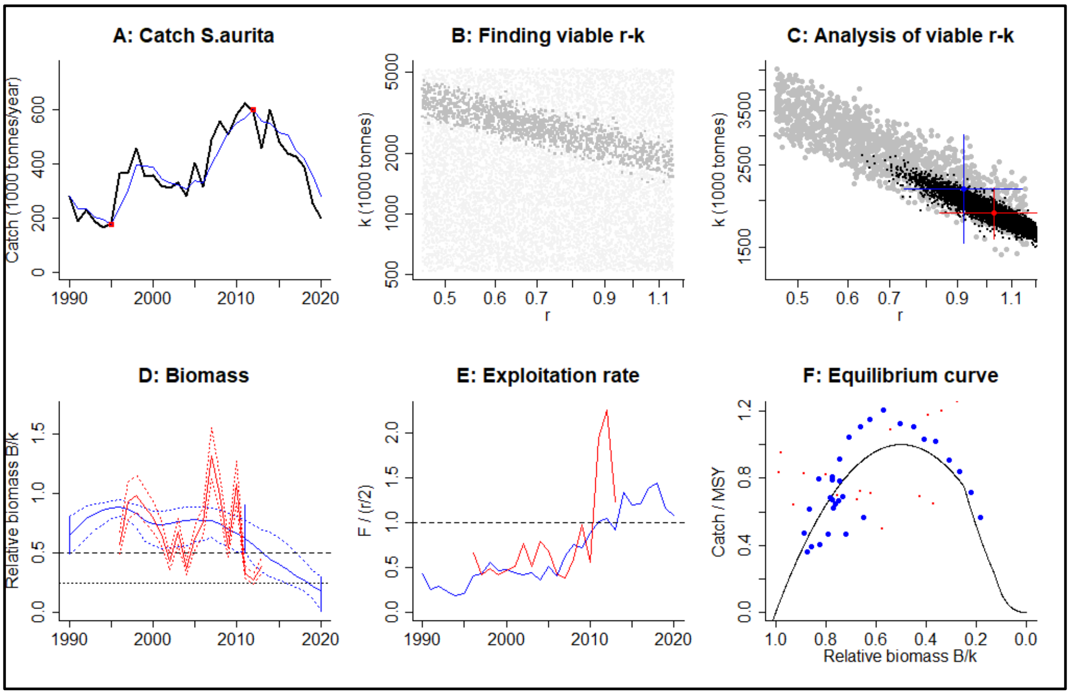


Figure 6. CMSY outputs for Sardinella aurita for Run 7.

The CMSY without CPUE gives a F/Fmsy=150% and B/Bmsy=0.366. On the other hand, the second method with CPUE gives a ratio F / Fmsy = 73.3% and B / Bmsy = 0.566. The results show a low biomass despite a reduction in fishing effort in 2019.

3.1.4. SPiCT

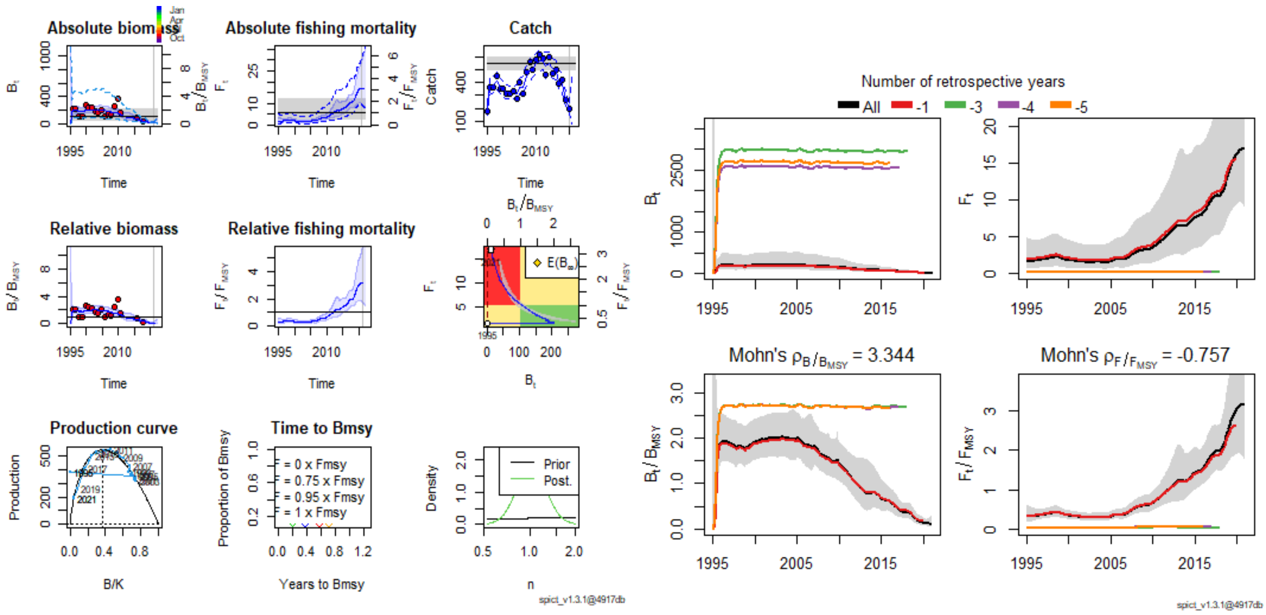
For *Sardinella aurita*, SPiCT was fitted using landings (t) and survey biomass estimates (t) time as input data. The configurations run followed the description in Table 4. For each Run the checklist for the acceptance of the SPiCT was performed:

- *Model convergence*. Runs 3-5 converged.
- *No violation of model assumptions based on one-step-ahead residuals (bias, autocorrelation, normality)*. In all cases no violations observed.
- *All variance parameters of the model parameters are finite should be TRUE*. In all cases the variance equal to true was achieved.
- *Consistent patterns in the retrospective analysis*. All configurations model showed inconsistence in the retrospective trends.

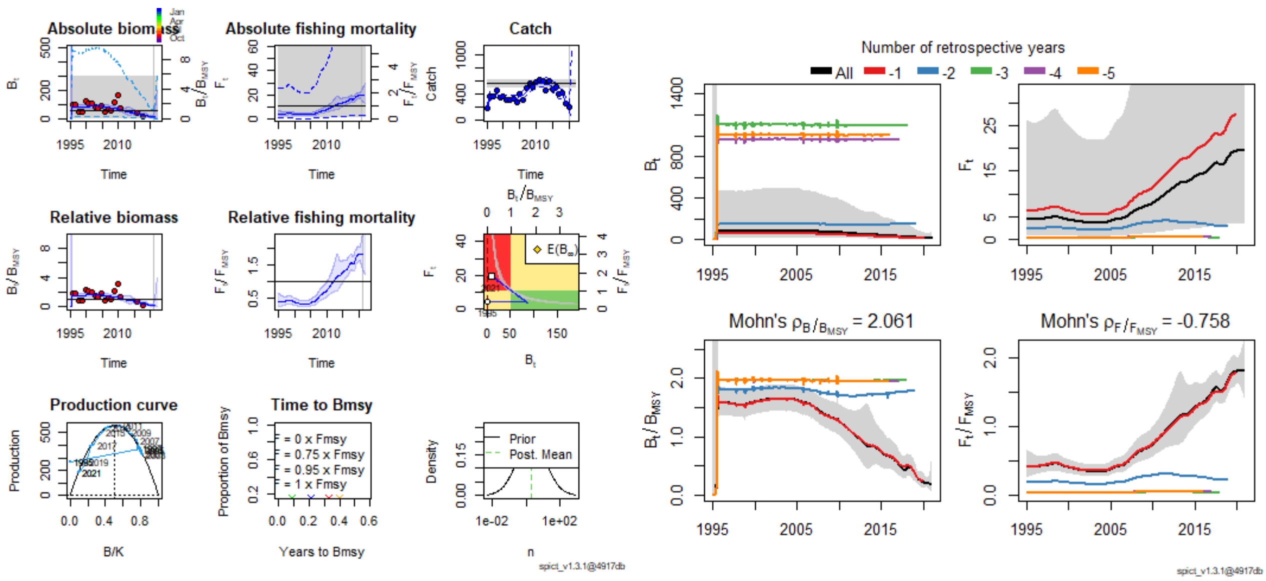
- *Realistic production curve*. In many cases the production curve was not realistic.
- *Check whether the same parameter estimates are obtained if using different initial values*. For each run 20 different trials were fitted but in many cases with different initial values models did not converge.
- *High assessment uncertainty can indicate a lack of contrast in the input data or violation of the ecological model assumptions. Confidence intervals for B/BMSY and F/FMSY should not span more than 1 order of magnitude*. In all cases the confidence intervals of both estimations did not spanned more than 1 order of magnitude.

Outputs of the Runs 3-5 are shown in Figure 7.

Run 3



Run 4



Run 5

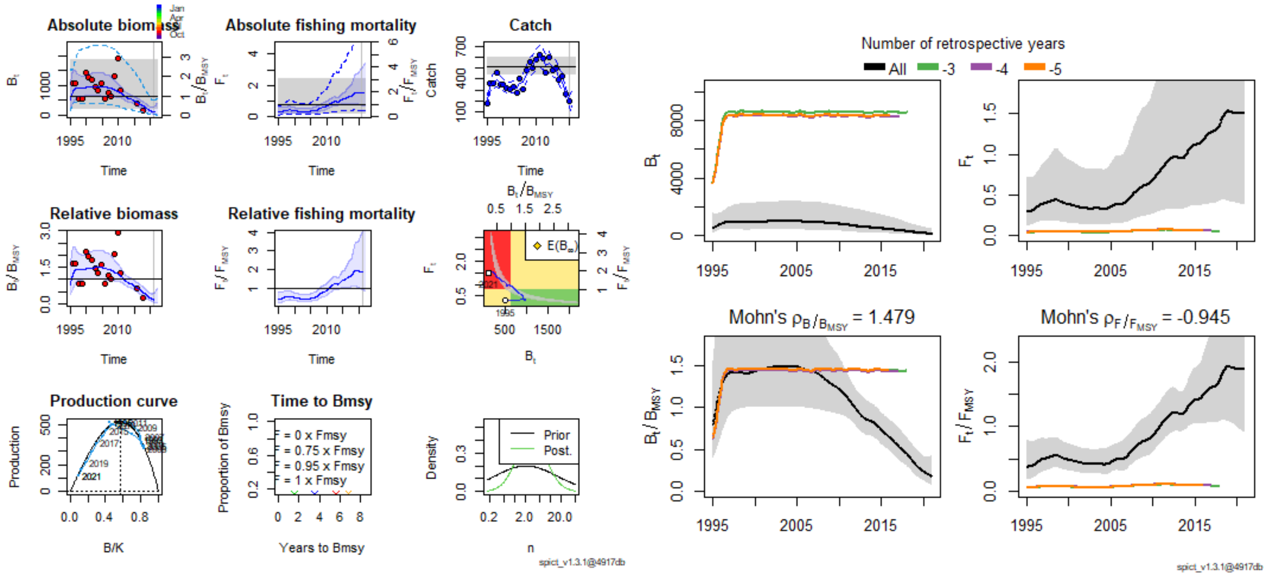


Figure 7. SPiCT outputs for *Sardinella aurita* for Runs 3-5.

4. Discussion

The **length-based approaches** tested in this analysis provide a very simple methodology with low data requirements which may provide an indication of stock status under equilibrium and steady state assumptions. In particular, they rely on the selection of parameter values used for L_{mat}, growth and natural mortality as they affect the absolute percentages of the indicators, although not their trends. Several of the reference points calculated were empirical and based on the von Bertalanffy growth parameter L_{inf}. Clearly, it is important that representative growth parameters are used in these approaches. However, it should also be noted that growth parameters may be uncertain for this stock. With regards to estimation and use of Lc as a fishery metric, the length distribution must represent catch (rather than landings only) if discards occur, which seems to be the case. Inclusion of discards may make difference to the overall status estimation. Furthermore, they are equilibrium-based methods, i.e. constant F and no recruitment variability. The assumption of constant (or modest, random variability in) recruitment causes some difficulties in practice. Strong year classes reduce the mean length, suggesting in the case of LBI high mortality when the situation is actually good (strong recruitment) and vice versa. The annual length frequency distributions were examined and no evidence of a strong year class entering the fishery and consequently modes migrating from left to right over time were found. However, annual length frequencies showed differences which may be due to a deficient sampling design and implementation. Fishery-independent data would be required to further explore the equilibrium assumption. In addition, the method is strongly sensitive to the selectivity pattern assumed and to the representativeness of the length data. Commercial selectivity is assumed to follow a logistic curve; however, this requires knowledge of the shape of the selectivity curve, which is not available for this stock. Validity of assumptions needs further examination. An approach could be to test the main assumptions (robustness to recruitment variability and dome selection), examine sensitivity to errors in model inputs, and simulate models based on diverse range of life histories (*M/k*).

The **CMSY** is dependent on good biomass prior ranges and is also sensitive to changes in their value. The analyses presented here highlight one of the weaknesses of the CMSY approach described in several reviews on assessment methods for limited data stocks (Geromont and Butterworth, 2015; Bouch *et al*., 2021): the reliability of the results obtained, in particular concerning the state of the stock in recent years depends directly on the plausibility of the information provided a priori on depletion rates. As found by Bouch *et al*. (2021), CMSY requires biomass priors that act as strict bounds for the B/BMSY status estimates, and the default rules quite often failed to correctly provide those bounds. Using expert knowledge to refine the biomass priors is recommended by Froese *et al*. (2017). There are significant issues in using expert knowledge to set the biomass depletion priors and the amount of confidence placed in them as what is observed are removals. Stock assessment is used to determine the depletion level of the stock, not rely on it being known beforehand. The estimated stock trajectories are somehow imposed by the user, by the choice of the priorities used on the depletion rates. Furthermore, warning should be taken about reduced recruitment at low stock sizes. Productivity models such as used by CMSY assume average recruitment across all stock sizes, including stock sizes below half of Bmsy, where fisheries textbooks predict an increased risk of reduced recruitment. In other words, if recruitment is indeed reduced, then CMSY will overestimate production of new biomass and will underestimate exploitation rates. Extra caution need to be applied when the assumption of average recruitment is likely to be incorrect, e.g. at stock sizes below half Bmsy or during periods known to be unfavourable for recruitment.

In the absence of a reliable assessment by the other model that can serve as a basis for the CMSY model, the relevance of the CMSY results is necessarily limited. These results should therefore be taken for illustrative purposes and should not be used to provide scientific advice.

SPiCT is a generalization of previous surplus production models in the sense that stochastic noise is included in both observation and processes of both fishing and biomass.

It was difficult to fit the model to the data. Additional information was included in the fit via the shape of the production curve (parameter n) and prior distributions for initial depletion to add stability to the model. Results did not provide an acceptable assessment of the stock status. Mostly of the models showed retro pattern reflecting the fact that although the model converged, the parameters were not well defined, which affected also the estimated biomass, F and corresponding reference points. From these results it can be inferred that available data are not informative enough for the model clearly estimates parameters. It is not possible being confident in the diagnostics that can be made on stock status from the results of the SPiCT model.

Both **CMSY and SPiCT** models contain process error, which means that a random deviation is allowed every year from the assumed deterministic production model (Schaefer or Pella-Tomlinson, respectively). One must be aware of the fact that, if the magnitude of the annual deviations associated with the process error gets large, the surplus production model assumption (e.g. Schaefer) will become less meaningful, in the sense that the population dynamics may be driven more strongly by the large annual deviations than by the Schaefer model. A potential consequence of this is that MSY reference points may be derived based on the production model (e.g. Schaefer) which actually does not represent the population dynamics well.

5. Conclusion

In conclusion, these exploratory runs assessments of the *Sardinella aurita* with multiple data-limited methods prove that **a quantitative assessment is not yet feasible and therefore it is not possible to provide scientific advice in terms of catch or effort limits based in these methodologies.**

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